AN EXPERT SYSTEM FOR THE STRATEGIC PLANNING OF CONSTRUCTION PROJECTS

Paper presented to the Conference "Computers in Quantity Surveying Practice", Tsinghua University, Beijing, China

28th November - 3rd December, 1988

Dr. R. MARTIN SKITMORE, MSc, PhD, FRICS, MCIOB

SENIOR LECTURER

THE UNIVERSITY OF SALFORD

ENGLAND

(Currently visiting fellow in the Department of

Building & Surveying, Hong Kong Polytechnic)

October 1988

AN EXPERT SYSTEM FOR THE STRATEGIC PLANNING OF CONSTRUCTION PROJECTS

Dr R M Skitmore MSc PhD FRICS MCIOB

Visiting Fellow from Salford University, England

ABSTRACT

This paper describes the instigation and development of an expert system to aid in the strategic planning of construction projects. The paper consists of four parts - the origin of the project, the development of the concepts needed for the proposed system, the building of the system itself, and assessment of its performance.

The origin of the project is outlined starting with the Japanese commitment to 5th generation computing together with the increasing local reaction to theory based prescriptive research in the field. The subsequent development of activities via the Alvey Commission and the RICS in conjunction with Salford University are traced culminating in the proposal and execution of the first major expert system to be built for the UK construction industry, subsequently recognised as one of the most successful of the expert system projects commissioned under the Alvey programme.

The conceptual framework within which the eventual system was developed is described. This consists of four 'modules' - initial budget, procurement, development appraisal, time - all linked and interfaced to a common information module.

The methodological aspects of the system construction are described as involving knowledge acquisition from selected 'experts', intermediate knowledge representation and analysis through inference net diagrams, and iterative 'validation' processes.

The final part describes the performance tests conducted on the system in terms of the accuracy of results, usability and usefulness in obtaining real business benefits.

Keywords: Expert systems, estimating, price forecasts, procurement, contract duration, development appraisal, knowledge acquisition.

THE ORIGIN OF THE PROJECT

The motivation for the project can be traced to two distinct sources. Firstly the growing awareness amongst researchers in the quantity surveying field that systems ought to incorporate in some way the human expertise element of quantity surveying activities and, secondly, the initiative being taken at national level to promote and encourage research into knowledge based systems generally.

Raftery (1987), for instance, has charted the progress of research in cost models as moving progressively towards more mathematically based techniques such as multiple regression analysis to the increasing exclusion of the subjective and often delicate judgemental abilities of the practitioner. The lack of any real sign of application of these relatively sophisticated techniques has, in Raftery's view at least, lead researcher into considering ways of bringing practitioner skills more formally into the technical development of systems.

In 1982, a central committee under the chairmanship of British Telecom's John Alvey examined the implications of Japanese Research into "5th Generation" computers for British Industry. As a result of this committee's deliberations, the British Government initiated a large investment programme to support joint research between industry and academia, under the control of the Alvey Directorate. One part of this programme concerns the development of Intelligent Knowledge Based Systems (IKBS) or, as they are sometimes called, Expert Systems.

In recognition of the changing direction of quantity surveying research and the opportunity offered by the Alvey programme to investigate the application of expert systems, the Royal Institution of Chartered Surveyors (RICS) applied for and successfully obtained a part of the research activities supported by the programme.

It is of interest to mote that the Alvey Directorate award to the RICS was the only one mode to the construction industry. It was therefore considered to be a significant and important research programme, not only for quantity surveying, but for all those professions and firms within the construction industry. The work has subsequently received a high commendation by Alvey Directorate representatives.

The project represents the work of the research team and their professional colleagues over a period of eighteen months commencing January 1986.

A full description of the project can be found in Brandon et al (1988).

THE CONCEPTUAL FRAMEWORK

It was considered essential that the Expert System should address the major problems of judgement exercised by quantity surveyors as this would demonstrate more clearly the potential of the new technology. Since the key element of the activity is to make 'fair' judgements between alternatives, the Expert System's utility was dependent on its ability to provide support in this area.

The task chosen was that of 'strategic planning' of construction projects in which the computer would gather relevant information of the client's needs and translate it into a strategy for the client, design team or independent consultants to follow. The Expert System would therefore provide assistance to the quantity surveyor, acting as Lead Consultant, in interpreting clients intentions into a framework for 'tactical' decision-making.

Thus, the major issues addressed by the system are :-

1. **financial budget** - how much money will be needed to get the kind of building required and the corresponding standard achievable.

2. **procurement** - what will be the most appropriate method of arranging the individual responsibilities of the design and construction teams in order to achieve the building on time with a satisfactory amount of flexibility.

3. **time** - what is a reasonable length of time for the feasibility, design and construction phases within the various project constraints.

4. **development appraisal** - what is the likely profitability of the scheme and/or how much money may be available to spend on the site etc.

In order to accommodate these facets of strategic thinking it was decided to develope the system in a modular format, each facet being represented by a module. As the modules are interdependent, some provision was clearly needed for interfacing information between modules. This was accommodated by means of a common **project database** containing both data provided by the user and the assumptions and recommendations derived by the system. The resulting conceptual framework for the system is illustrated in figure 1.

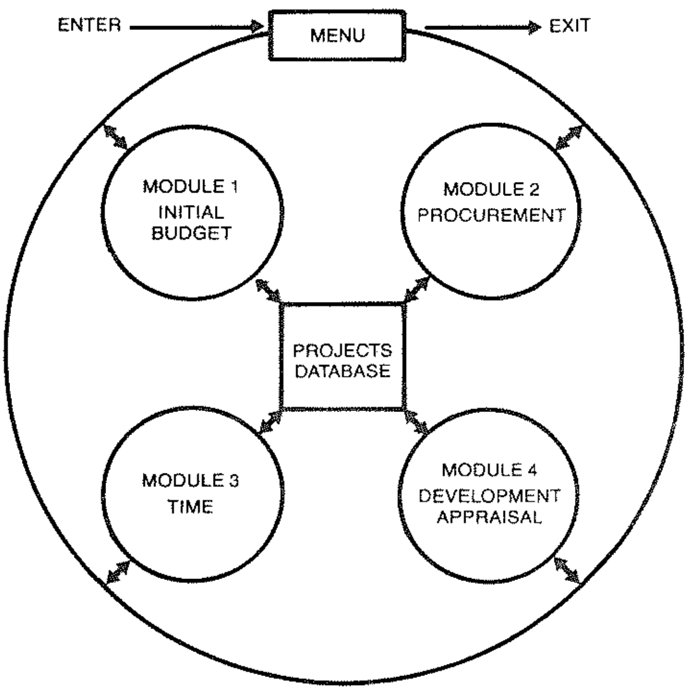

Figure 1 Conceptual Overview of the System

Entry into the system is through a menu. This menu allow the user to go to any one of the four Modules in any order. If time is the most important consideration then this may be the first Module to be accessed. On the other hand if cost is critical then financial budget may be more appropriate. As questions are asked in each Module so the answers are fed into the data base. Where this information is common to another Module the next Module program will investigate the data base before asking a question to see whether this information is already known. If it is, it will collect the information and not ask the question.

Each module therefore represents a different problem for the Expert System to solve :-

FINANCIAL BUDGET

This is an 'intelligent front end' to a conventional estimating model. It translates the client's requirements into a hypothetical design which can then be quantified and costed using unit rates in the conventional way.

PROCUREMENT

This is a planning problem. The activities that need to be undertaken are prompted and identified. An optimum time is then suggested for each activity and these times are then aggregated together.

TIME

This is a planning problem. The activities that need to be undertaken are prompted and identified. An optimum time is then suggested for each activity and these times are then aggregated together.

DEVELOPMENT APPRAISAL

This program interacts with a conventional valuation model, and provides additional knowledge as to certain input values e.g. fees.

The outputs obtained from the four Modules explain the reasoning and the assumptions that have been made. Consequently the model is 'transparent' to the user, and since the logical processes follow that of the human expert, the user should quickly build up confidence in the system. This is in contrast to many mathematical models which tend to be of a 'black box' nature where the user is excluded from a knowledge of the processes and the derivation of the assumptions.

A particular feature of the system is the manner in which the expert can interact with the program. 'What-if' type questions may be asked and assumptions made by the machine may be overridden. Fine tuning of the proposal, sensitivity analysis and introduction of constraints are left within the control of the user. There is therefore the opportunity for the user to drive the program if desired.

METHODOLOGY

1. <u>The research team and collaborators</u>

The research team, based at the University of Salford, was headed by Professor Peter Brandon and comprised two knowledge engineers, a chartered quantity surveyor and full-time secretary. The 'industrial' collaborators were headed by members of the Quantity Surveyors Division of the RICS who were represented for practical reasons by a small group of surveyors from private practice, contracting, central and local government who formed the user group.

2. <u>Knowledge acquisition</u>

Figure 2 shows the Knowledge Acquisition process in outline.

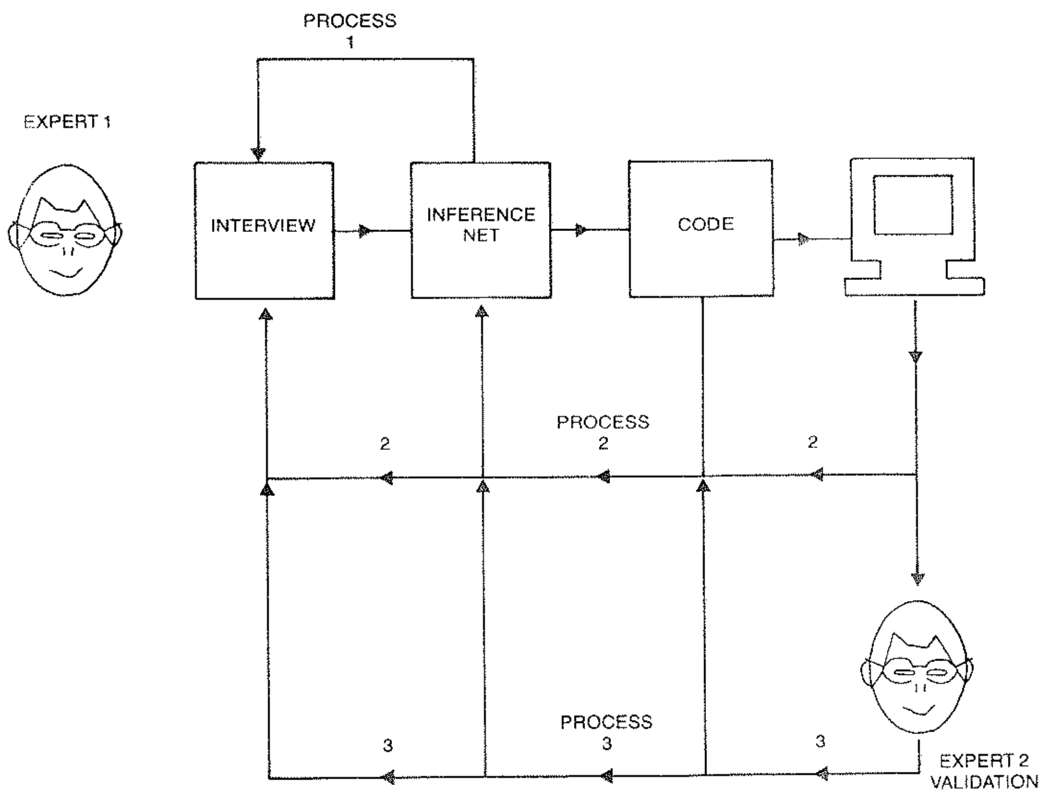

Figure 2 Approach to Knowledge Acquisition

The firms in the User Group were divided into two subgroups for each Module. One subgroup was used to provide the knowledge whereas the second set was used to validate the program developed from the knowledge. It was an iterative process with the 'providers' being asked to check each stage before it was passed to the 'validators'.

The interview process usually began with an explanation of the subject with the expert to establish the objective of the expert system, the nature of their knowledge, the context for decision making and the alternative approaches to solving the problem. In subsequent interviews the discussions centred around the 'goals' or advice to be given and the variables which influenced the selection of a particular target. Once these were identified the relationships and additional factors which linked the 'variables' with the 'goals' were investigated until a picture of how a choice was made was completed. This was represented in an inference net diagram, see figure 3, which provided a useful visual check to the knowledge. This paper model of the knowledge allowed the expert to test his own reasoning quickly and simply (process 1). If a problem was identified it could be quickly remedied on the sheet, before coding began.

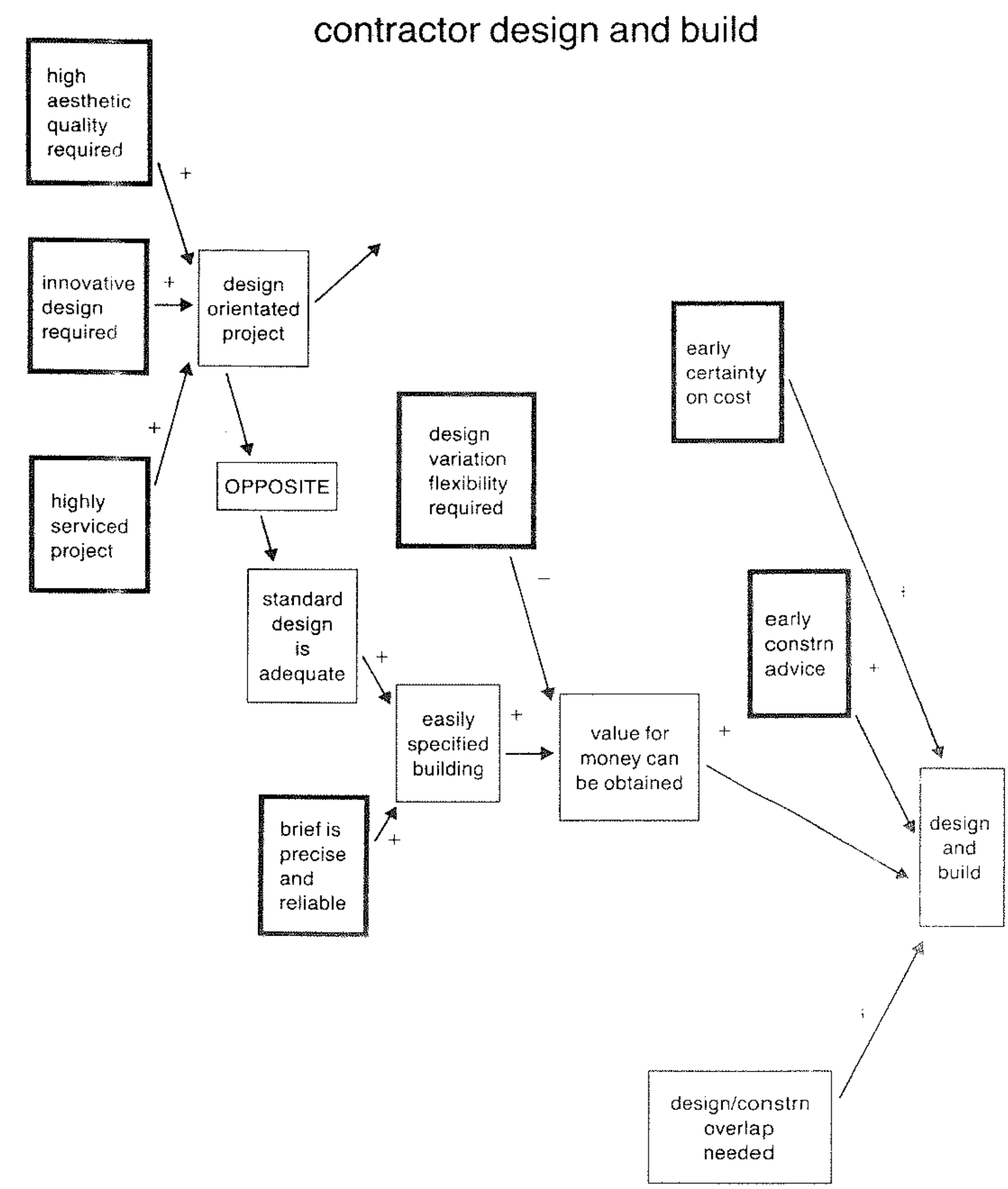

Figure . .3 Inference Net Diagram relating to the choice of Design and Build Procurement Path.

After coding into the machine the iterative process continued with testing of the resultant program by the knowledge provider (process 2). This could result in further interviews or more distant testing by means of a questionnaire or self assessment. In practice for a particular facet of the system, it usually took three or four half day interviews to gain the knowledge and one or two further interviews to complete the process to the satisfaction of the expert.

Once a suitable first draft was formulated it was then passed to the independent validator whose main task was to test the final product against their own knowledge and experience. It was usual for the projects in the validators office to be used as the test bed for this check. If anomalies arose they were corrected in a similar way to the previous iterative process (process 3).

Where there was an obvious conflict of opinion then the 'providers' and 'validators' would meet to try and achieve a consensus. The knowledge engineer would provide a clear statement of the conflict and discussion would take place around this statement. Generally speaking the matter could be resolved by further investigation of the causal factors underlying the different viewpoints. In a very few instances where consensus was not achieved it was necessary to take the view of the majority.

In due course it was usual for both 'providers' and 'validators' to meet and discuss the final product and seek further refinements. The programs were also demonstrated to other members of the User Group not involved with the Module in order to achieve wider exposure and testing. It is worth noting that many of the firms also engaged several of their senior personnel in the validation process and therefore it is likely that ten or more of particulars will have viewed the program before release.

PERFORMANCE

1. Budget module

The BUDGET Module was tested by distributing discs to the twelve members of the User Group, and asking them to run the system, against real case studies as far as possible. The group were also supplied with a detailed proforma, on which they were asked to record their answers to questions, their overridings, the results, and any remarks they had. The evaluators have been in private practice, local and central government.

About 40 building projects have been submitted to it, over a period of 6 months.

Although the performance of the system is still being evaluated it is possible to comment on the following areas :-

- accuracy of result,
- usability,
- usefulness in obtaining real business benefits.

Accuracy of results

The result offered by the BUDGET Module is not the first estimate it makes, but rather the estimate produced after a few parameters have been overridden to take into account what is already known or assumed about the building. Obviously, if the user had to override many items it would mean that the ability of the Module to predict a suitable 'design' was deficient. On the other hand, it is expected that the user will have to override some assumptions made. All buildings differ and the number of combinations of specification and form are for practical purposes infinite. So an arbitrary figure of half-a-dozen overridgings was considered acceptable. Moreover, it must be relatively easy for the user to know which items need overriding.

In the early days it was found that the user would see the Module's estimate and say "That's about right". There was no way of knowing whether this was a true statement, so the Module was adapted to ask users for their estimate of the cost of the building before and after the main questions were asked, but before the result was declared. The reason for asking this question twice was in case the initial consultation made users after their original opinion.

In general, the cost of building as predicted by the Module is claimed to be within about 5% of that predicted by the expert Quantity Surveyor. Surprisingly, perhaps, it has performed well on the more complex buildings. There have, however, been a few cases where the inaccuracy has been greater.

In one case the Module's estimate disagreed with the QS's estimate but agreed with the actual Tender price when it came in! Usually it is difficult to know where any fault lies (as it is when comparing estimators' forecasting the cost of a project at this stage).

Usability

Usability is a measure of how convenient the user finds the Module in use for real projects, whether or not it gives accurate estimates, and how easy and fast it is in use. Things that increase the usability include the facility for changing items, the facility for storing the information in a Projects Database, the reporting of assumptions made and the graph of cost against quality.

It is difficult to gain anything other than a subjective assessment of usability, but the users so far have generally been pleased with it. They have also found it relatively easy to use, in that they have not required detailed user manuals. Most of the responses they are required to make are as might be expected. Users like the reports that give the assumptions behind the decisions made; this lends a certain attractive 'transparency' to the Module.

The speed of operation may give cause for concern in the future, since on an IBM-PC-AT there is a delay of about 5 seconds between answering certain questions and being asked the next. These are the items that link to almost everywhere in the Knowledge Base, and so their answer is propagated throughout it. The BUDGET Module Knowledge Base has about 1500 items in its main part. However, speed may not be much of a problem to many users.

<u>Usefulness</u>

It has not been possible yet to ascertain the real usefulness of the BUDGET Module. The benefits obtained will depend heavily on the role given to the Module within the organisation. They are likely to include faster estimates, the ability to allow less senior staff to obtain estimates of building cost, or to perform an initial estimate that a more experienced surveyor will later check, the ability to keep records of a (long-term) project, accepting ever more precise information as the project proceeds, and its possible use in training. Its printed report, suitably modified, may be able to form the basis of a report to the client. Lastly, there may be some role in helping firm up the client's brief.

2. Procurement module

Policy on procurement is at present in a state of transition with widely differing views held as to the extent of the potential benefits and disadvantages of the more recently introduced methods.

Procurement decisions are made infrequently and under widely varying conditions where a wide range of interrelated factors can be responsible for the success or otherwise of a project and it is difficult to disentangle the effect of one from the other.

It was therefore not possible to accurately validate the performance of the Module against a 'real' project because the solution actually used cannot be guaranteed as being the best and success will depend on the competence and skill of the parties involved.

The main benefit of the program is seen as the provision of explanations in the evaluation of the different procurement methods rather than the ratings themselves. This is because the ratings given depend on the precise weightings attributed to each factor influencing the decision. The weightings arrived at are inevitably somewhat subjective since it is difficult to isolate the influence of any particular aspect from the others.

Nevertheless a high degree of consensus was found on the issues that are highlighted when the program is used. The sensitivity analysis facilities allow the user to explore the consequences of different project 'scenarios' (e.g. varying project size, the requirement for early certainty on cost, building service content) on procurement policy in a way that is not easily done otherwise.

3. <u>Time module</u>

The aim of the TIME Module is to produce quick and realistic project duration forecasts, at the earliest stages of the building process.

The system is able to demonstrate, both 'graphically' (in bar chart format) and in text/numerical format the effect on overall project programme of changes in the decisions made early in the project organisation.

It also justifies its advice by providing the assumptions made from information input during the consultation.

Comments on the performance of the Module after consultation involving a number of projects include the following :-

- The construction periods compared favourably with those encountered on 'actual' projects.

- The duration of the feasibility and procurement phases differed considerably from those incurred on 'actual' projects due to the affects of factors outside of the scope of system consideration.

- The system gives a fair assessment of project duration at the early stage (inception of the project).

4. Development appraisal module

Some projects may deviate to a significant extent from the standard S-curve pattern of expenditure used by the DHSS, in that the distribution of expenditure over the construction period may be more 'front loaded' than a typical project, other projects by contrast may be 'back loaded'. Two examples of special cases are given below to illustrate this point :

'front loaded' project: built site with a retained facade in the City, extensive substructure to be provided

'back loaded' period: greenfield site on firm soil with easy access, heavy services content, high quality finishes

Outline principles on how experts adjust the S-curve to take such cases into account have been elicited and recorded for possible future reference but have not been included at this stage.

Rounding errors

Since the residual calculations are fairly lengthy slight rounding errors are likely to occur. The worst case is when the years purchase is calculated for periods other than perpetuity; exponentials are involved and an error of about 0.5% arises. Since the residual result is particularly sensitive to this parameter an error of nearly 5% can occur on a residual land value in these circumstances.

Validation

Performance evaluation through the distribution of copies of the system to members of the User Group for their trial usage on real world projects is currently underway but no problems have been identified to date.

DOMAIN SUITABILITY

1. Budget module

Expert Systems technology, particularly as represented by mature software like SAVOIR, is well suited to setting a financial budget for a building project although there are still certain areas of difficulty.

Suitability

The basic requirements for early budget-setting are :

i) That the modelling approach generally involves estimating a cost and then obtaining some indication of how the cost varies in response to variation in requirement or in unforeseen external constraints. If the Client is not certain about the type of external walls needed or if it is possible that site problems may occur, then the budget must be raised to take account of such uncertainty.

ii) The knowledge required to make the estimate is, in many places, judgmental in form, and has to take into account preferences and the acceptability/demand for such things as flat roofs or Air Conditioning.

iii) The knowledge required is complex, with many interlinkings, and it is subject to change as fashions or technologies change. Ease of encapsulating and modifying knowledge is therefore vital.

iv) It is one thing to accurately encapsulate judgmental, complex knowledge. It is another to make that knowledge usable. Facilities for storing information in a database and for providing Help are needed.

Expert System technology, as represented by SAVOIR, is well able to handle this kind of knowledge. It allows the uncertainties in (i) and (ii) above to be handled in two ways - by probabilistic reasoning and by allowing values to be altered in a What-if- fashion. The former is used to handle preferences, judgements and allocation of plussages for contingency while the latter is used where design decisions have to be made but are subsequently open to alteration. With its declarative form, whereby the main Quantity Surveying knowledge is kept separate from details of how it is used, Expert System technology is well able to handle the complexity referred to in (iii) above. Finally, SAVOIR can provide the usability features in (iv).

<u>Areas of difficulty</u>

The area of difficulty for Expert System technology concerns visual information like building shape and form. Expert System technology cannot handle this in anything other than the most general fashion.

Given a site of a certain shape and the need to get a certain amount of office space onto it, there are, in general, several building shapes that will suffice. The choice between these shapes often depends on internal layout of functional space as well as site factors like direction of slope, situation of the main road, proximity of neighbouring buildings and position of underground cables, tunnels etc. The human expert copes with these matters by a visual assessment of the site and codified information such as maps and drawings.

To handle this within the Expert System would involve a huge amount of extra knowledge - both of the detailed layout of the site and architectural knowledge. These factors can affect cost, but for Expert Systems technology to be usefully employed it has been necessary for shape information to be held in a fairly coarse form within the various complexity factors.

2. Procurement module

Procurement policy was found to be an inherently problematic field for the development of an Expert System providing definitive advice. This was because experts in this field are very heavily dependent on experience and rely on an intuitive appreciation of the factors involved.

No typical ways were identified to describe the thought processes involved, or justifications used, in a procurement decision.

The important achievement of the PROCUREMENT Module was to develop and make explicit the outlines of a decision making method where none existed previously.

The program has codified a good deal of knowledge related to procurement which is not found in text books. It does provide a useful datum which can be refined and altered over time as more objective information becomes available and fashions change. The personal qualities of the consultant together with his or her experience do have a major effect however, and this should not be forgotten when interpreting the results of the program.

Thus the PROCUREMENT Module is not so much a system that dispenses expert advice, but rather an intelligent assistant that helps the lead consultant ask the right questions, indicates likely problem areas, and gives a second opinion.

3. <u>Time module</u>

The suitability of Expert System technology to forecast project duration early in the building process was considered in terms of its attributes and the benefits provided by the system produced.

<u>Attributes</u>

The following Expert System attributes were considered particularly useful in developing this Module :

- Advice may be offered in a situation where information for decision making is uncertain.

Advice on likely project duration may be required to establish the feasibility of a scheme. For instance, if a Client needs to move offices within a defined time the constraint may be in selecting between acquiring an existing building or constructing a new one.

- Knowledge is built in to produce solutions both efficiently and effectively, using the short cuts or 'rules of thumb' that human experts use to eliminate wasteful or unnecessary calculations.

- Indirect benefits may accrue, apart from those obtained from a working system, by extracting and recording previously undocumented knowledge and expertise which may otherwise be lost through retirement, staff loss or transfer.

- Actual expertise is used as the basis of the Module knowledge. Detailed explanations of the systems operation are provided and assumptions are made explicit which promote confidence and faith in the results. It is also easy to establish the effect of a change on the system operation.

Benefits

The following benefits were identified as provided by the system developed :

- Sound advice can be given to the Client, on the basis of limited data, at an early stage.

- The Client can be given a variety of options together with advice on the implications.

- Many Chartered Quantity Surveying practices will have access to knowledge not currently available to them.

- A framework and checklist for a consistent approach to the problem has been produced.

For the role adopted it was agreed by the TIME Working Group members that the system worked effectively and had potential as a useful tool to Quantity Surveyors in providing rapid advice to Clients.

If, however, the role of TIME was expanded to monitor project progress throughout the building process it is likely that the suitability of Expert Systems in the prediction of time would reduce. This is because the emphasis of the system would change from the manipulation of knowledge (Expert System) to the manipulation of data (Conventional Program).

4. Development appraisal module

Although a conventional program language could have been used to produce a calculation program for DEVELOPMENT APPRAISAL, the use of an Expert System has provided the following advantages :

- linkage between the four Modules forming the overall system has been more easily achieved than with a conventional program.

- the system has the flexibility to incorporate additional complex knowledge with little difficulty.

EPILOGUE

The Expert System described in this paper is now available for purchase in the UK. Copyright restrictions are such that the system cannot be sold or lent to anyone outside the UK. It is possible, however, that Expert systems may be developed along the same lines as the one described in terms of concept, methodology and presentation. Indeed, Salford University is very keen that such developments take place. Should anyone wish to build a similar system, either inside or outside the UK, the writer will be very happy to provide any advice or information needed.

REFERENCES

1. Brandon, P.S., Basden, A., Hamilton, I.W., Stockley, J.E. (1988) Expert Systems: The Strategic Planning of Construction Projects Royal Institution of Chartered Surveyors.

2. Raftery, J. (1987) Chartered Quantity Surveyor Vol. 9, No. 10, May p.20 "Cost Models: An Interim Valuation".